

derivatives of elastic properties has been clearly identified in this study, but some possibilities may be suggested. Most measurements seem to have been done with the transducer bonded directly to the sample, and many of those measurements were done by the method described by *McSkimin* [1961] and *McSkimin and Andreatch* [1962]. If their procedure is closely followed, in particular, if the carrier frequency is fixed at the zero pressure (free) resonance frequency of the transducer and the correction made for the change of the resonance frequency with pressure, then the effect of the bond on the pressure derivatives of elastic moduli should amount to less than 0.02. If the transducer correction is neglected, an error of the order of 0.1 might be incurred in the modulus derivative. If, in any experimental procedure in which the transducer is bonded to the sample, the carrier frequency deviates more than a few percent from the transducer resonance frequency, then the bond phase shift might cause significant error, especially if the deviation is at zero pressure, where the bond effects are largest. Measurements reported here demonstrate an error of 5% in the slope (i.e., about 0.25 in the pressure derivative of modulus) incurred by operating a 10 Mhz transducer at 32 Mhz rather than 30 Mhz.

On the other hand, it seems that measurements made with buffer rods between transducers and samples may be subject to significant errors unless special precautions are taken. It has been estimated here that a conventional bond between the buffer and sample could change the measured modulus derivative by the order of 0.25, a very thin bond (such as was apparently achieved here by immersing a lapped contact in a liquid pressure medium) would produce a somewhat smaller effect, perhaps of the order of 0.05. The ratio of buffer to sample acoustic impedance should be significantly different from (preferably less than) unity, to reduce the bond phase shift.

It seems that the (not unreasonable) hope of *Spetzler et al.* [1969a,b; also, *Spetzler*, 1970; *Spetzler et al.*, 1972] of avoiding the bond (or interface) phase shift by using a dry lapped contact has not been completely borne out by the results reported here, at least for compressional waves. Dry lapped contact seems to produce substantial phase shifts in compressional waves. Since the mechanism producing the phase shift is not understood at present, its pressure dependence cannot be estimated, but it could easily produce substantial errors in measured pressure derivatives. With what is inferred to have been a partially wetted lapped contact, even larger phase shifts were observed at zero pressure. As indicated above, no anomalous buffer-sample interface phase shifts were observed for shear waves.

Further study, especially with buffer rods, should clarify these problems. In particular, a careful comparison at zero pressure (which was not achieved in the present study) of the relative phases measured with the transducer on the sample and with the various buffer rod-sample contacts should identify unambiguously which of the buffer-sample contacts are producing anomalous phase

shifts. Then, more measurements under pressure are required, both to confirm the expected effects of "normal" buffer-sample bonds and to determine the pressure dependence of the "anomalous" interface phase shifts.

Finally, we note again that the effects of transducer bonds can account for significant systematic errors, especially in the measurement of first and higher order pressure derivatives of elastic constants. The results of this paper show that such effects are in accord with theoretical predictions; consequently it is possible to correct for them. But in order to correct for such effects one must know the details of the experimental procedure, such as the operating frequency of the transducer. We strongly recommend that such details be routinely included in published reports, so that the effects of these and possibly other yet unknown systematic errors can be corrected for without repeating the experiment.

Acknowledgments. We are grateful to J. Peter Watt for assistance in computer program development, and to H. Spetzler for useful discussions. This research was supported by the Committee on Experimental Geology and Geophysics, Harvard University, and by National Science Foundation Grant GA38899 (Earth Sciences).

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